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16. ABSTRACT

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The Responses of Prairie Deer Mice to a Field SO_2 Gradient

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ABSTRACT

A capture-mark-release study of deer mice (Peromyscus maniculatus) was conducted on two 10-acre grassland areas (Zonal Air Pollution Systems or ZAPS) at monthly intervals from April to September 1976. Both areas were subdivided into four in-line experimental plots, with three smaller plots as buffer zones. Each of four experimental plots was fumigated at a median SO_2 concentration of nearly 0 (control), 2.2 (low), 3.9 (medium) and 6.5 (high) pphm, respectively. Three functional groups of mice were recognized: resident adults and juveniles (group 1); transient adults and juveniles (group 2); and resident and transient adults (group 3). Temporal displacement and numerical replacement of group 1 was directed toward areas of lower SO_2 concentration. Members of group 2, especially juveniles, were trapped more frequently on the control and low SO_2 plots on ZAPS 2, but transient juveniles were virtually absent from ZAPS 1. Recruitment of group 3 onto the control plots at both ZAPS occurred more rapidly than onto other plots in late summer. Throughout most of the trapping period, the number of occupied traps on all fumigated plots decreased relative to control plots on both ZAPS, and remained relatively higher on control plots from mid-season to the experiment's conclusion.

THE EFFECTS OF COAL-DERIVED AIR POLLUTION upon terrestrial vertebrate biota and associated ecological processes are incompletely known. In particular, open-field experiments employing low-levels of individual or groups of pollutants for extended periods are conspicuously absent from the expanding body of biological information of other pollutant effects on both aquatic and terrestrial ecosystems (1, 2, 3)*. Vertebrate responses to polluted areas may be reflected in altered reproductive processes, increased mortality, or behavioral adjustments, such as minimizing exposure to the polluted phase of the environment or emigration out of the polluted area. Regardless of the mode of pollutant action, the end result may involve resource depletion, which in this study denotes a loss of species diversity or abundance. This study was an attempt to evaluate the long-term potential for depletion of the small mammal resource within an open field SO_2 pollution gradient, as well as to alleviate in part the hiatus between short-term laboratory experiments, which involve acute and direct exposure of one or more pollutants to an organism, and quantitative animal inventories of impacted areas.

The study was one component of the EPA-sponsored Colstrip, Montana, Coal-fired Power Plant Project, which is designated to investigate pollution effects on grassland ecosystems (4). Although several species of small mammals were encountered in this study, this paper focuses upon the responses of the prairie deer mouse (Peromyscus maniculatus) to sulfur dioxide, a known toxic contaminant emitted from coal-burning power plants. The objective was to ascertain trends in animal movements within the gradient and to determine capture and recapture frequencies at each plot within each ZAPS.

*Numbers in parenthesis designate references at end of paper.

METHODS

STUDY SITE DESCRIPTION - The 1976 investigation was conducted on each of two 10-acre (4.0 hectares) ungrazed grassland parks concurrently in use for other studies and located within Custer National Forest in southeast Montana. Each site is on a 6-8% southwest facing slope at 1220 meters elevation. The fumigation apparatus is thoroughly described elsewhere in these proceedings (5), but the general outlay is shown in Figure 1. The control (plot A) and experimental (plots B, C and D) were fumigated at median levels of nearly 0, 1.7, 3.5, and 5.6 pphm SO_2 at ZAPS 1 and nearly 0, 2.9, 4.3, and 7.5 pphm SO_2 at ZAPS 2, respectively. These plots were uniform in size (1.54 acres), habitat, edaphic, and terrain features at each site. Buffer areas between plots (i_1, i_2, i_3; 1.29 acres each) received some SO_2 indirectly from adjacent fumigated plots, but were not monitored for SO_2. The two zonal air pollution systems (ZAPS) were 1.7 km apart. ZAPS 1 operated continuously during the 1975 growing season, and both ZAPS 1 and 2 operated during the 1976 season.

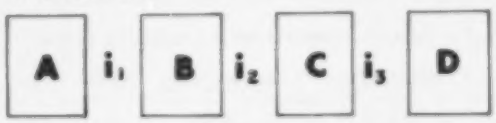

Fig. 1 - A schematic of the ZAPS grid system.

TRAPPING PROCEDURE - Both treatment and interval plots were trapped over a period of five months (Table 1). Twenty-five Sherman live traps were placed within each experimental and control plot in a 5 x 5 pattern with a 50 x 56 foot spacing between traps, with 20 traps in each interval plot (i_1, i_2, i_3) in a 5 x 4 pattern with distances of 56 and 40 feet between traps. Traps were prebaited with rolled oats for two days followed by three days of capture-mark-release (CMR). One week of CMR was conducted just before the onset of the fumigation period. Animals under study were toe-clipped and their body weight, length, sex, age, reproductive status, pelage color and molt phase were recorded. Age was determined by the combined use of weight and length, pelage color,

Table 1 - 1976 Trapping periods

	CMR period[1]		Day No.
1.	9-11 Apr	(prefumigation)	1
2.	13-15 Apr	(postfumigation)	4
3.	12-14 May	"	33
4.	23-25 Jun	"	75
5.	28-30 Jul	"	110
6.	25-27 Aug	"	138
7.	15-17 Sep	"	159

[1]capture-mark-release

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and genital appearance. Animals not classed as adults were termed juveniles.

Individually marked traps were opened between 1800 and 2000 hr and checked the following morning on days of CMR. Traps remained open all day during prebaiting periods. Records of both trap number and animal number made possible the determination of areas of capture, movement patterns of resident animals, and visitations to individual traps. Most commonly encountered were the deer mouse (P. maniculatus) and prairie vole (Microtus ochrogaster) and the diurnal 13-lined ground squirrel (Spermophilus tridecemlineatus).

DEFINITIONS - Several terms used throughout this paper require a brief description:

(1) Adult--a sexually mature animal, characterized by a minimum body weight of 15 g, developed sexual or lactating organs, and adult pelage color.

(2) Juvenile--a sexually immature animal, not fulfilling the definition of an adult.

(3) Resident--an adult or juvenile trapped in successive trapping periods, not necessarily sequential.

(4) Transient--an animal trapped only once during a trapping period, and at no time thereafter.

(5) Trapping period--two days of prebaiting followed by three of CMR.

(6) Activity--the total number of animals trapped, including recaptures, during any trapping period.

RESULTS

The numbers and proportions of mice and voles trapped at both ZAPS sites over 6720 trap-nights were similar (Table 2), despite greater canopy cover, 27% more precipitation, and higher SO_2 levels at ZAPS 2.

Table 2 - Species composition at trapping sites[1]

Site	M. ochrogaster	P. maniculatus	Other	Total
ZAPS 1	26 (23.2%)	86 (76.8%)	0	112
ZAPS 2	38 (26.8%)	101 (71.1%)	3[2]	142

[1]numbers exclude sciurids; numbers in parentheses are percent of total.
[2]includes two species of mice and one gopher.

The sex and age distribution of deer mice on each ZAPS are presented in Figure 2. Only two juveniles were trapped at ZAPS 1 for the period Apr-Aug, while 17 were caught at ZAPS 2 during this time. No detectable responses to SO_2 were noted in voles, and in fact none were trapped on control plots. The vast majority of voles at both sites were trapped on plot B (low SO_2) and on intervals i_1 and i_2. The vole's aggressiveness and tendency to form dense colonies seems to have resulted in the exclusion of deer mice from vole territories. Thus, substantially fewer deer mice were trapped on plot B. Although this patchy distribution of voles was nearly identical at both ZAPS, greatly facilitating intersite comparison, it did not permit any correlation of vole distribution with the SO_2 gradient. Hence, voles are not included in the analysis hereafter. The extent to which voles may have interfered with deer mouse emigration is not known. However, few mice were ever trapped in areas containing large vole colonies. This apparent exclusion occurred mainly on the north end of plot B of ZAPS 2.

The following assumptions were made in the interpretation of the results. First, terrain and habitat features are similar on all plots at both ZAPS so that habitat preference is assumed to not influence the results. Second, the chances that an animal may traverse a plot or be trapped within any one plot are assumed to be equal for all plots.

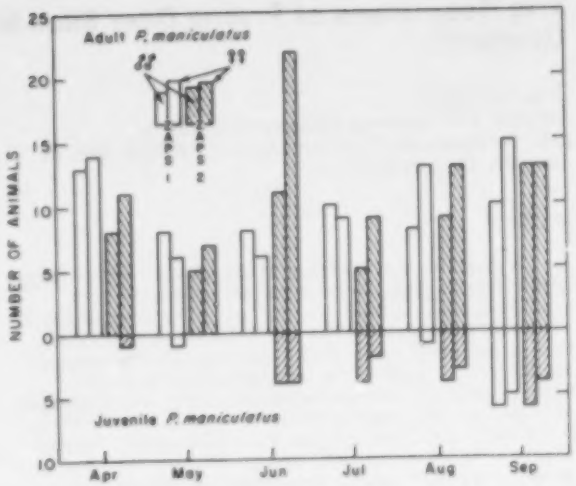

Fig. 2 - Sex and age composition of Peromyscus at ZAPS 1 and 2.

The null hypothesis is that immigration or recruitment onto any portion of the ZAPS proceeds unimpeded as if no SO_2 were present. On the contrary, if a mouse or vole is sensitive to SO_2 at these levels, its response to test plots should be different in space and time from that of control plots.

Three functional groups of mice were recognized: resident adults and juveniles, transient adults and juveniles, and resident and transient adults. Because juveniles are often dispersing to find new territories, a category of resident and transient juveniles as a stable population unit probably did not exist. These three groups form the basis of the following discussion.

CAPTURE PATTERNS OF RESIDENT MICE - Because the burrow sites of resident mice were not determined, a mouse that lives within a fumigated plot could not be distinguished from one that lives outside it but returns to the trap for food. No trapping was conducted beyond the borders of test or interval plots. Therefore, no resident movements other than those parallel to and within the gradient could be ascertained. The criteria for movement within this zone were:

(1) capture at least twice in the area of initial capture followed by successive captures in another interval or plot at least 150 feet away;

(2) capture in the new area at least once in a future trapping period.

At ZAPS 1, 16% (eight mice) of all mice trapped (26% of all residents) fulfilled these criteria, and at ZAPS 2 these figures were 5.3% (four mice) of all mice trapped (11.1% of all residents). Of these 12 mice, seven moved down and five up the gradient. Six of the seven moving down were initially trapped on plot D (high SO_2) and one of the adjacent interval. Of the 5 moving up the gradient, three originated at plot A, one at plot B, and one at C. None of these moved into plot D. At least two explanations are possible. First, if the burrows of permanent residents were not within the ZAPS, these mice may not be affected by exposure to SO_2 while entrapped. The lure of plentiful food then outweighed any discomfort a mouse experienced during its stay within test plots. It is equally possible that those residents showing movement may have had their burrows on the ZAPS and moved accordingly in response to SO_2. Second, if most residents had burrows within the ZAPS, they may

not have been sufficiently repulsed by SO_2 to elicit large scale emigration. In addition, the number of residents with burrows on the ZAPS that emigrated shortly after exposure to SO_2 in April cannot be determined. If captured only once, these mice are by definition transients. Any number of mice that were so misclassified would undermine the observation that a small percentage of residents moved out of the SO_2 field.

TEMPORAL CAPTURE PATTERNS OF RESIDENT AND TRANSIENT ADULTS - The temporal changes in adult mice trapped on each ZAPS site (recaptures excluded) are depicted in Figure 3. Juvenile mice have been omitted because of the profound discrepancy between juveniles trapped on ZAPS 1 and on ZAPS 2, thereby precluding equitable comparison of mice of all age groups. These graphs show that while mice on plots C and D are relatively stable and low, control plots show enhanced recruitment throughout the season, especially in ZAPS 1. The low

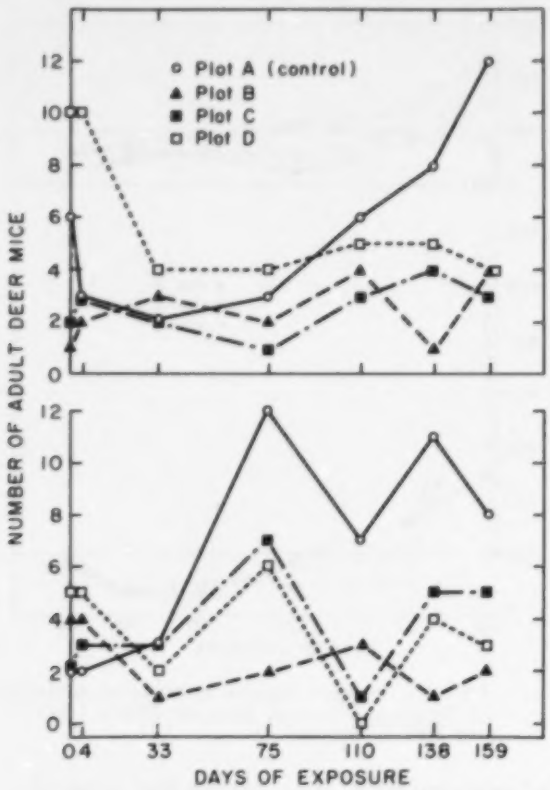

Fig. 3 - Temporal changes in numbers of adult Peromyscus on test plots at ZAPS 1 (top) and ZAPS 2 (bottom).

numbers of mice observed on plot B can be attributed to the presence of voles. It can also be shown that totals of adult mice summed May to September differ significantly on plots A, C and D, with plot B excluded for the reason given above (Table 3). April is not included because of three days between initial and post-fumigation CMR were thought to be insufficient for SO_2 to achieve a noticeable effect on animal populations, although data for April at ZAPS 2 indicate that effects may have been felt within this period.

CAPTURE PATTERNS OF TRANSIENT MICE - Transients often form a large fraction of trapped populations (6). Transients were represented at ZAPS 1 by 38% and at ZAPS 2 by 52.6%. If the SO_2 gradient exerts no effect upon transients moving across test plots and the assumptions mentioned earlier are valid, then transient mice should appear in traps in approximately equal numbers on all plots, although there may be unbalanced numbers in both sex and age classes (6). Because fewer transients were trapped on ZAPS 1, the following analysis has been simplified by treating the control and low plots and interval i_1 as one section (Ai_1B) and plots C and D and interval i_3 as another (Ci_3D). Animals in the middle interval were assigned to one unit or another, depending on proximity of capture to either unit.

Several hypotheses were tested in this analysis:

(1) the numbers of adult and juvenile transients trapped in section Ai_1B should equal approximately those trapped in section Ci_3D.

(2) the numbers of adult transients should be comparable on plots A and D.

(3) the numbers of juvenile transients should be comparable on plots A and D.

(4) juvenile transients should be evenly distributed across each ZAPS.

(5) adult transients should be evenly distributed across each ZAPS.

The results of this analysis are summarized in Table 4.

ZAPS 1 and ZAPS 2 are dissimilar with respect to hypothesis 1, and hypotheses 3 and 4 do not hold at ZAPS 2. An effect of SO_2 on the behavior of transient mice, especially juveniles (compare hypotheses 4 and 5) is indicated. However, many juveniles were trapped on all plots in September, but because no trapping was conducted in October, these mice cannot be classified as transients or residents. Hence, the hypothesized SO_2 sensitivity difference between adults and juveniles cannot be fully supported. Another unexplained observation is that with one exception in May all transients trapped on section Ci_3D at ZAPS 2 were caught in June, whereas on other parts of ZAPS 2 they were trapped at all times, except in May when none were caught. No comparable data exist for ZAPS 1 except in September, thus precluding any deductions based upon independent observations in time. In this foregoing analysis, the presence of voles has been ignored, but their presence on plots B, i_1 and i_2 serves to accent the difference observed with regard to hypotheses 1, 3, 4 and to some extent 2 because of the presumed increase in mice trapped at plot B in the absence of voles.

CAPTURE PATTERNS AT INDIVIDUAL PLOTS - For each plot animal activity was summed throughout all trapping periods for both peripheral and interior portions of each fumigated plot as well as for each interval. Peripheral portions were the 16 traps forming the boundary of each plot, and the remaining nine traps

Table 3 - X^2 Analysis of season totals of adult mice (May to September).

Plot	A		C		D		
Site	Observed	Expected	Observed	Expected	Observed	Expected	X^2
ZAPS 1	31	14.4	13	18.6	22	14.4	24.6[1]
ZAPS 2	41	18.9	21	21.6	15	16.9	34.8[1]

[1] $P<0.001$

Table 4 - Transient movement and distribution

Hypothesis number	Site	Data	X^2, P	Hypothesis supported
1	ZAPS 1	9, 10	0.11, 0.26	Yes
	ZAPS 2	29, 12	7.07, 0.99	No
2	ZAPS 1	7, 5	0.42, 0.48	Yes
	ZAPS 2	13, 7	1.85, 0.83	Yes
3	ZAPS 1	--	--	insufficient data
	ZAPS 2	12, 0	10.1, 0.99	No
4	ZAPS 1	--	--	insufficient data
	ZAPS 2	19, 8	3.70, 0.95	No
5	ZAPS 1	13, 12	0.08, 0.22	Yes
	ZAPS 2	15, 13	0.18, 0.33	Yes

formed the interior portions. Two hypotheses were tested. First, peripheral activity and second, interior activity of all plots should be comparable. Assuming that a large number of mice live outside each ZAPS and are attracted to the bait (62% of all activity occurred in the peripheral boundary of each ZAPS), these hypotheses predict that as the boundary traps "filter" immigrants or nearby residents seeking food, they should be first occupied and therefore contain a larger fraction of trapped mice. The hypotheses also predict that when peripheral traps, which are within the fumigated areas on experimental plots, are filled with mice, interior traps should fill at equal rates if SO_2 inhalation does not affect foraging behavior. The data pertaining to activity with peripheral and interior regions of each plot are shown in Table 5.

Table 5 - Regional activity summaries at each plot

Plot	A		B		C		D	
Region	P[1]	I[1]	P	I	P	I	P	I
ZAPS 1	40	30	35	7	33	14	42	24
ZAPS 2	55	28	48	11	48	14	48	7

[1]P and I refer to peripheral and interior activity.

There was no statistically significant difference in peripheral activity among plots (X^2 = 5.95, P = 0.88 for ZAPS 1 and X^2 = 0.74, P = 0.35 for ZAPS 2). Plot B was eliminated in the goodness of fit tests for interior activity because of the apparent vole inhibition of deer mouse activity. While peripheral activity was shown to be similar among all plots, interior activity was reduced on plots C and D of ZAPS 2 (X^2 = 15.22, P = 0.99) but not on ZAPS 1 (X^2 = 5.96, P = 0.88) owing to results at plot D. When the effect of time is considered, however, it can be shown that 42% of the interior activity on ZAPS 1 occurred during the first three days of fumigation in April. If the April figures are not included, the I values for ZAPS 1 become 27, 6, 8, and 16 for the respective plots of A to D (X^2 = 27.4, P = 0.99).

TEMPORAL CHANGES IN RELATIVE ACTIVITY - Figure 4 illustrates the seasonal changes in numbers of transient and resident adult and juvenile activity within each experimental plot relative to the control plot. At both ZAPS sites, there was a downward trend on all three experimental plots after the initial surge of activity, which might be explained by the initial exposure of each ZAPS to SO_2. The relatively low levels of activity in plot B can probably be attributed to the presence of voles. Because this pattern is

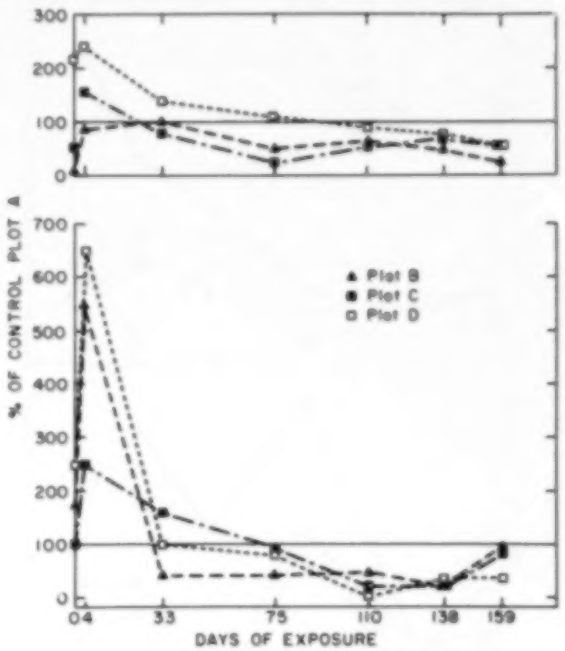

Fig. 4 - Temporal changes in relative activity of Peromyscus on test plots at ZAPS 1 (top) and ZAPS 2 (bottom).

duplicated spatially, it is unlikely that variables other than SO_2 could exist simultaneously at both sites and elicit the same pattern. These data then provide some of the strongest evidence for the effects of chronic low levels of SO_2 upon animal behavior.

CORRELATION BETWEEN ACTIVITY AND SO_2 LEVELS - Hourly means of SO_2 (pphm) were averaged over 12 hr periods (1800 to 0600) on nights of CMR. Averages for all three nights of each trapping period were computed and examined against the activity of deer mice. No correlations were apparent. These results are expected for several reasons. First, SO_2 levels often varied substantially throughout each 12 hr period. Averaging SO_2 levels obscures real differences between hours or blocks of hours that might have correlated with activity if the times of capture were known. Second, any correlation would imply an immediate behavioral response to SO_2. Although it is not known how a small mammal initially responds to SO_2

inhalation, the results of this experiment show that some mice may tolerate SO_2 levels employed in this study for long periods. For example, some mice at both ZAPS were trapped each month or nearly every month. Hence it would appear that in addition to any direct effect of SO_2 on an animal, there may be indirect effects as well operating through various pathways, e.g., food and water quality or abundance, or habitat characteristics.

DISCUSSION

Obvious drawbacks to this field study were the innumerable variables that were not controlled, could not be controlled, or which were not employed in the data analysis (e.g., micrometerological data). Yet, several lines of evidence presented in this paper indicate that chronic low levels of SO_2 affect free ranging populations of deer mice. Although no physiological data on SO_2 affected mice have been accumulated, the trapping data suggest that baited traps attract more mice on control rather than on fumigated plots. These data further suggest that the effects of fumigation are integrated over time, there being no perceptible correlations between plots and animal activity within or between adjacent trapping periods. Two important findings of this study are that sampling must occur over relatively long periods to acquire interpretable results and that the same experiment replicated in space and time showed similar results. Similar data collected in 1977 on a smaller scale (no interval plot trapping; three trapping periods July to September) also support the 1976 findings. Trapping activity on plots A and B combined was double that at plots C and D on both ZAPS, although the establishment of a vole colony at plot D on ZAPS 2 may have depressed mouse activity, thereby inflating this activity ratio were no voles present.

Although deer mice may be more susceptible to air pollution, or at least SO_2, than are voles, the sensitivity of the vole and thus its usefulness to air pollution studies has yet to be determined. Generic differences between Microtus and Peromyscus to at least one pesticide has been documented (7). Long-term toxicological effects of endrin were demonstrated in unenclosed populations of Peromyscus maniculatus but not Microtus pennsylvanicus. Both the deer mouse and microtines contribute to the vigor of grassland ecosystems and other areas of undisturbed habitat (8, 9). The widespread distribution of the deer mouse in North America suggests, however, that it might serve as an information base for further studies of air pollution in the northern Great Plains, especially in those areas likely to be impacted by coal development and (or) coal burning. To accomplish this, baseline population data and empirical evidence supporting physiological damage to mice from chronic low-levels of air pollution should be collected. In addition, more rigorous techniques should be developed to evaluate the behavioral responses of deer mice to pollution challenge.

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